# THE HURRICANE SEASON OF 1960

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## 1. GENERAL SUMMARY

The hurricane season of 1960 was subnormal from the standpoints of both frequency and intensity. Seven tropical cyclones developed in the Atlantic and four reached hurricane intensity (fig. 1). However, only one hurricane—Donna—was of major intensity, although Ethel may have been so for a few hours. Donna was the most destructive hurricane ever to strike Florida and one of the most damaging ever to affect the United States. It is also believed to have caused hurricane winds over a greater proportion of the United States coastline than any other known hurricane. Tropical cyclones were well distributed throughout the season except in October which was remarkably free from even the weak disturbed conditions normally observed in the Tropics. Tracks of the tropical cyclones are shown in figure 1.

The mean 700-mb. circulation for June [1] was attended by above normal heights in the Atlantic over most areas north of 30° N. and below normal over most of the Tropics and subtropics. This circulation type is usually associated with at least normal tropical cyclone activity. The June cyclone (unnamed) formed in a manner described by Riehl [2] in which a westerly trough of large amplitude extending well into the Tropics fractures and the southern portion retrogrades followed by the development of a tropical cyclone.

The maximum positive 700-mb. height anomaly in the Atlantic for July was about 150 feet in the middle Atlantic between 40° and 50° N. with a United States east coast trough of considerable amplitude [3]. Normal tropical cyclone frequency in the Atlantic area during July is only one storm every two years [4]; thus the two tropical cyclones represent considerably above normal activity. Abby developed in very low latitudes and did not come under the influence of the east coast trough. Indeed, much of Abby's track (fig. 1) was along the lowest latitude of record for July.

The formation of Brenda was rather similar to that of the unnamed June storm.

Stark [5] noted a major reversal in the large-scale 700-mb. mean circulation over North America and adjacent ocean areas between the first and last halves of August. The belt of positive height anomalies shifted northward from 30°–40° N. during the first half to 40°–50° N. during the latter half of the month. Although heights remained near or above normal through most of the Tropics and subtropics—a condition not very favorable for tropical cyclone formation—the circulation during the latter half of the month more nearly conformed to the favorable type described by Ballenzweig [6] and Cleo formed on the 18th.

In contrast to the subnormal activity in the Atlantic, tropical cyclone frequency in the western Pacific in August was unprecedented [5]. Eleven storms were reported, nine reaching typhoon intensity. A positive 700-mb. height anomaly was located some 1000 miles east of Japan with a negative anomaly over Formosa (possibly in part due to some six tropical cyclones tracked over or near the area) resulting in unusually deep easterlies in the formation area.

Tropical cyclone activity was normal during September with two hurricanes, one tropical storm, and several tropical disturbances which moved along paths rather similar to those of Donna and Florence (fig. 1) but never reached storm intensity. The 700-mb. anomaly pattern in the Atlantic agreed rather well with the composite chart described by Ballenzweig [7] as favorable for tropical cyclone development. The mean circulation for September was predominantly one of high index and the axis of mean 700-mb. zonal wind speed maximum was displaced a substantial distance north of normal over North America [8].

Tropical cyclone activity in the Atlantic was nonexistent during October. The mean circulation for the month in the Atlantic area was most unusual [9]. Due to blocking, the subtropical ridge and maximum westerly winds were displaced to the south of their normal positions.

All but two of the 1960 North Atlantic tropical cyclones developed in or reached the Gulf of Mexico and all recurvatures in the Tropics and subtropics were west of longitude 70° (fig. 1) indicating an Azores-Bermuda anticyclone of considerable constancy and strength June through September.

Damage and fatality statistics are shown in table 1. Estimates are necessarily approximate. In Donna's damage total for Florida, citrus damage has not been included although 30 percent of the grapefruit and 10 percent of the oranges were lost. The subsequent increase in citrus prices is thought to have compensated for the crop damage. Insurance companies paid off about $90,000,000 in property losses in Florida and it is esti-

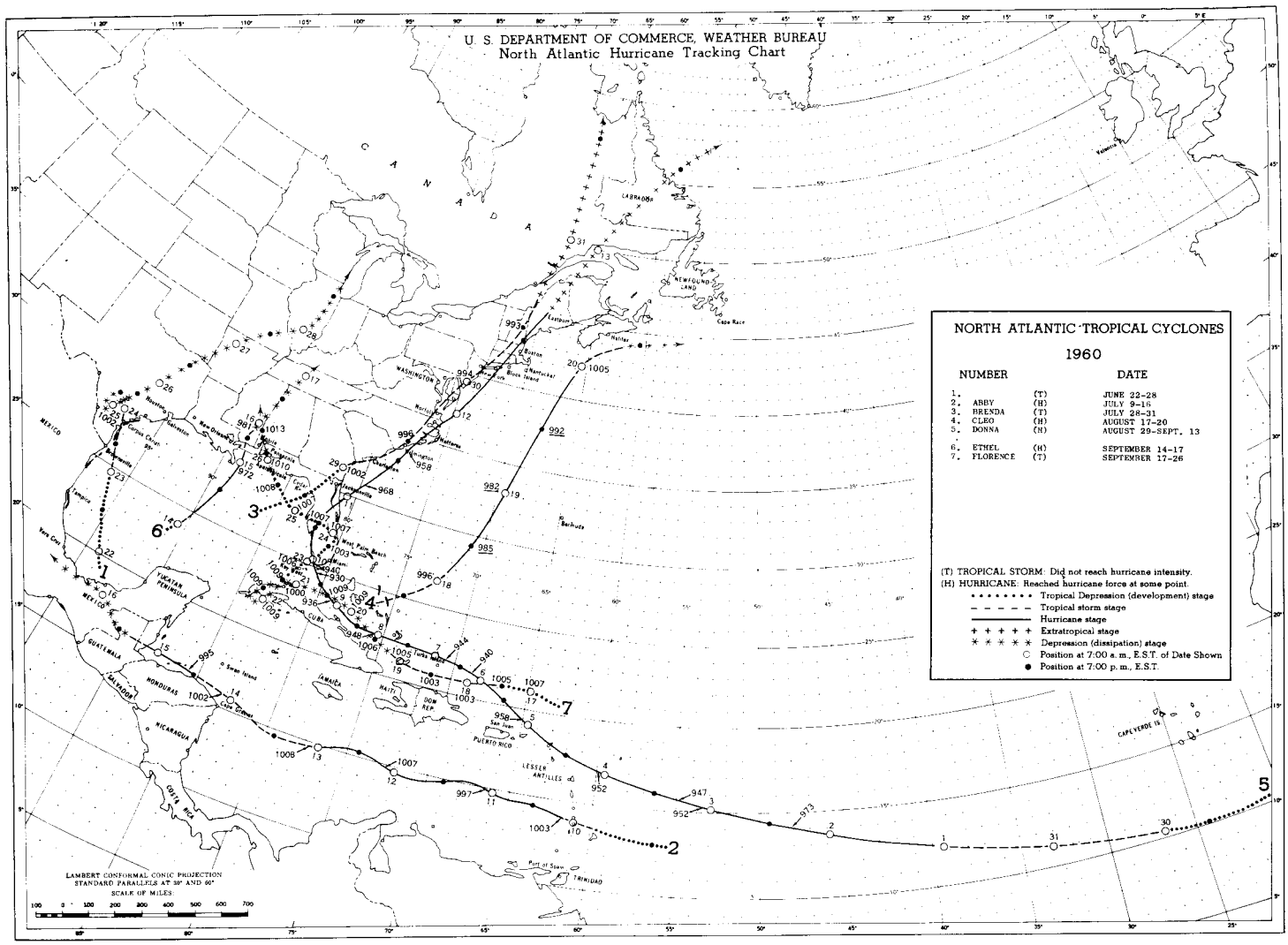


FIGURE 1.—Tracks of North Atlantic tropical cyclones, 1960, with minimum pressures. Underlined pressures in Cleo are estimated as function of observed winds.

mated about one-third of the property damaged was insured.

## 2. INDIVIDUAL TROPICAL CYCLONES

*Tropical Storm (unnamed), June 22–28.*—A routine reconnaissance flight into the extreme southwestern Gulf of Mexico on June 22 found a large mass of weather including heavy thunderstorms and squally winds up to 35 kt. The lowest observed pressure along the reconnaissance track was 1008 mb. with no circulation reported, although the Mexican coastal stations did indicate a slight circulation.

On the morning of June 23 the 200-mb. level had become more favorable for intensification and the barometer had fallen significantly along the Mexican coast from Tampico to Brownsville indicating a northerly drift of the disturbed condition. A Navy reconnaissance plane was dispatched to the area and found maximum winds of only 15 kt. but sea level pressure of 1006 mb. However, it is believed the plane did not fly under the most severe weather.

During the night of June 23–24 the tropical storm moved

TABLE 1.—*Fatality and damage statistics, North Atlantic tropical cyclones of 1960*

| Storm | Intensity | Date | Damage | Deaths | Principal areas affected |
|---|---|---|---|---|---|
| Unnamed | Storm | June 23–26 | $3,600,000 | 15 | Texas. |
| Abby | Hurricane | July 10 | 600,000 | 6 | St. Lucia, Martinique. |
| | | July 15 | slight | 0 | Honduras, Br. Honduras. |
| Brenda | Storm | July 28–29 | 5,000,000 | 0 | Florida. |
| Cleo | Hurricane | Aug. 17–20 | slight | 0 | Off-shore Atlantic. |
| Donna | Hurricane | Sept. 9–12 | 300,000,000 | 13 | Florida. |
| | | | 56,500,000 | 8 | North Carolina. |
| | | | 30,000,000 | 29 | Elsewhere U.S. |
| | | | 13,000,000 | 114 | Antilles and Bahamas. |
| | | | 400,000,000 | 164 | All areas. |
| Ethel | Hurricane | Sept. 14–15 | 1,060,000 | 0 | Central Gulf Coast. |
| Florence | Storm | Sept. 22–26 | slight | 0 | Florida. |
| Total within United States | | | $396,160,000+ | 65 | |
| " outside United States | | | 13,600,000+ | 120 | |

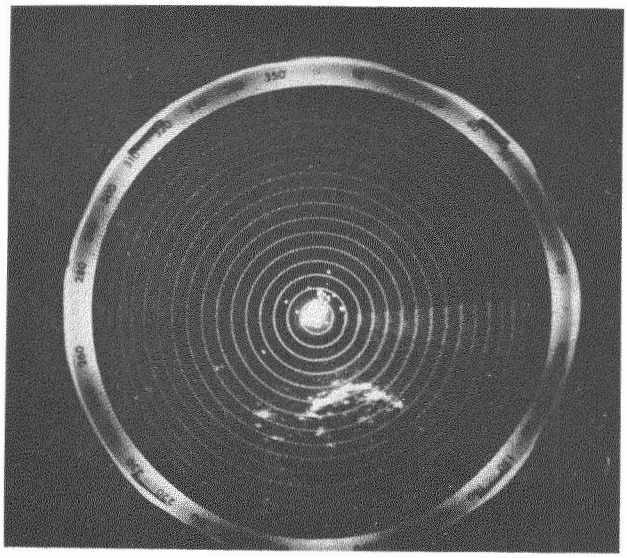

FIGURE 2.—First rain band of tropical storm of June 23, 1960, showing characteristic curvature. Taken at Freeport, Tex. Range markers at 20 statute miles. Photo courtesy Dow Chemical Co.

inland, south and about 30 miles west of Corpus Christi, Tex. Rockport reported sustained winds of 40 m.p.h. with gusts to 60 and Padre Island Park 50 m.p.h. with gusts to 60. The lowest reported pressure was 1002.4 mb. at Alice at 0300 CST on the 24th. Corpus Christi reported a tide of 3.5 ft. above mean low water. It appears that there was no wall cloud. There was some mild curvature on the rain bands seen on airborne radar on the 23d and the Dow Chemical Co. radar at Freeport near noon on the 23d reported a characteristically curved rain band (fig. 2). Apparent cloud centers were reported by radars at Victoria and Kelly Air Force Base on several occasions. Three fishing piers were wrecked on Copano Bay; one shrimp boat sank with three lives lost, and another was beached. The storm moved very slowly on June 24–25 attended by heavy rains of 5 to 15 inches or more from Corpus Christi to San Antonio and northeastward with considerable flooding. Port Lavaca reported 29.76 inches of rain for the period June 23–26. Tornadoes were reported on the 26th as the dying storm moved north-northeastward. Unusually heavy rains extended into Arkansas and southern Illinois.

Fifteen persons apparently were drowned either in the high seas or subsequent floods. Damage, mostly from the floods, is estimated at $3,600,000.

*Hurricane Abby, July 9–16.*—The first indication of the disturbance which finally grew into hurricane Abby was received from a ship about 3.5° east of the island of Barbados, at 0500 EST on July 9. Showery weather was reported with east-southeast winds of near 40 kt. Some shower activity had been occurring in the Lesser Antilles, and 24-hour pressure changes were small but negative. At 0100 EST on the 10th, a report received from the SS *Del Oro*, located at 13.8° N., 59.7° W., with sea level pressure of 1007.6 mb. and wind ENE 45 kt., indicated a strong easterly wave or a small vortex. A small center passed just to the north of Barbados during the next few hours.

At 0800 EST July 10, an advisory was issued on tropical storm Abby, based on reports from the Leeward Islands and a few ships. The storm was moving toward the west-northwest and was forecast to reach hurricane intensity during the day. Reconnaissance aircraft were dispatched to the area and confirmed the existence of hurricane Abby by 1100 EST. Highest winds were estimated at 90–100 m.p.h. over a small area near the center. Gale warnings and a hurricane watch were ordered for the Virgin Islands and Puerto Rico and for the island of Hispaniola as the hurricane moved westward.

On July 11 and 12, the hurricane continued on a westerly course, with doubt concerning its intensity. From reconnaissance aircraft and surface ship reports, it appeared to be rather poorly organized and much of the time was barely discernible on aircraft radar. By the morning of the 13th, the hurricane had diminished in intensity, with maximum winds estimated at 60 m.p.h. in a few squalls near the center in the northern semicircle. By early morning of the 14th, the storm had reintensified to hurricane strength with highest winds of 80 m.p.h. estimated by reconnaissance aircraft. The hurricane retained this strength but remained quite small in size as it skirted along the northern cost of Honduras, passing inland in extreme southern British Honduras early on the morning of the 15th. Advisories were discontinued after the cyclone moved inland.

Considerable rain occurred in Central America from Honduras north-northwestward into most of southern Mexico and the Gulf of Campeche as the remnants of Abby continued west-northwestward over the land area. Reconnaissance aircraft in the southwestern Gulf of Mexico on the 16th confirmed that the radar center of circulation did not emerge over the Gulf of Campeche but remained over the rugged terrain of the Isthmus of Tehuantepec.

An airborne radar picture of Abby (fig. 3), as the storm just about attained hurricane intensity off the northwestern tip of St. Lucia, shows the characteristic figure-nine and the asymmetrical cloud and precipitation pattern in the early formative stage at low latitudes. Only in a few squalls in the main rain band on the north and east sides were hurricane winds occurring. The radar picture in figure 4 on the morning of July 15 as the hurricane was approaching the coast of British Honduras shows a hurricane with a perfectly round eye and complete wall cloud. The eye was apparently not observed by the Swan Island radar as it passed within approximately 70 n. mi. of the station the day before.

At 500 mb. on July 8 and 9, the subtropical ridge was centered over Florida at about latitude 27° N. and extended eastward into the Atlantic north of the Antilles

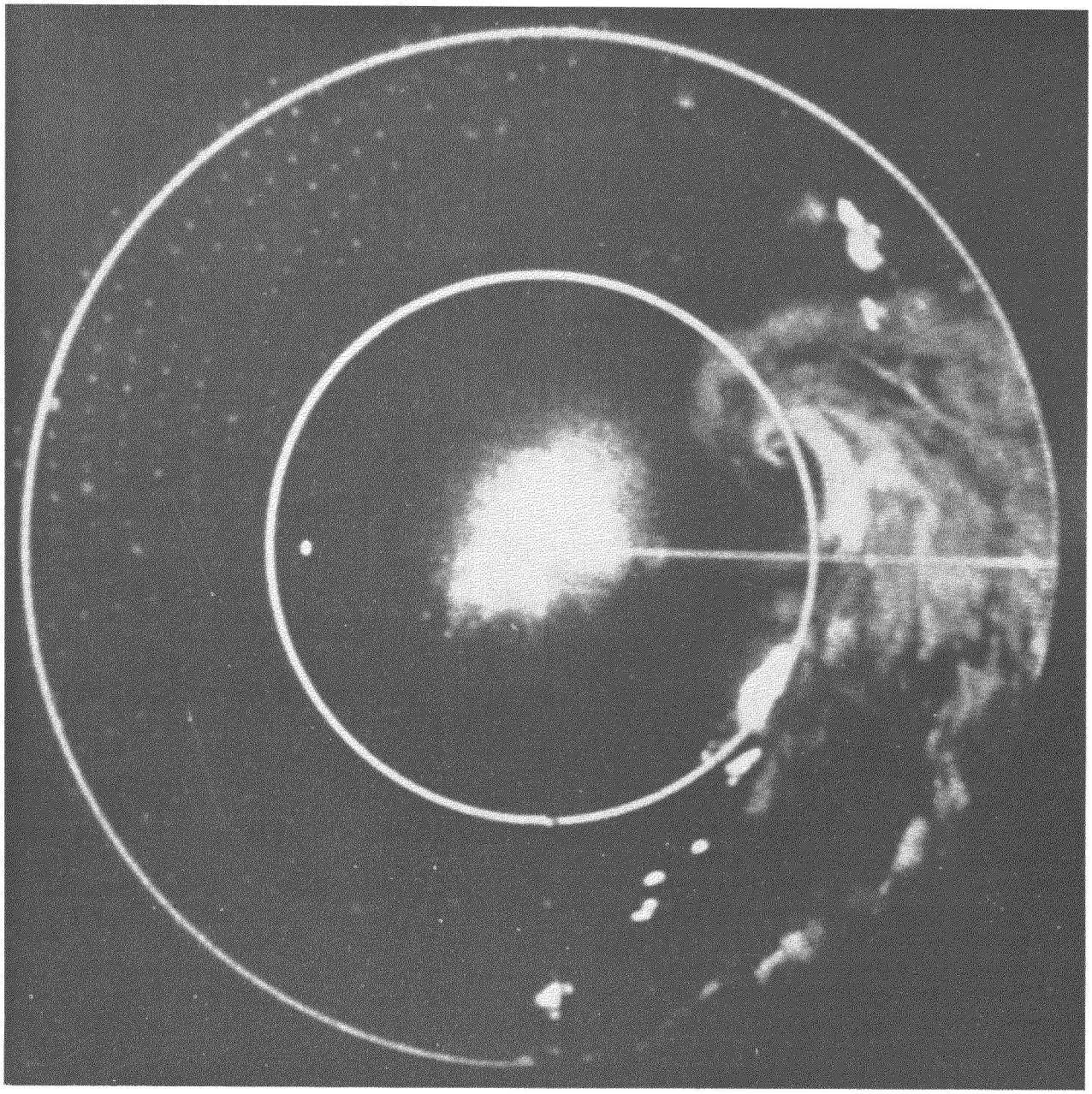

FIGURE 3.—Airborne radar picture of hurricane Abby in formative stages off St. Lucia. Note the characteristic figure-9 echo of a developing storm. Official U. S. Navy photo.

at about the same latitude. Easterly winds 10 to 20 kt. prevailed at Trinidad and northward across the Leeward and Windward Islands. By 1900 EST of the 9th, the winds had become light easterly at Trinidad and backed to northeasterly and increased substantially in the Windward Islands. The winds remained easterly and of moderate speeds in the Antilles until Abby passed inland over the Yucatan Peninsula.

Only minor fluctuations were noted in winds at 500 mb. at Curaçao and San Andres, the direction remaining easterly and the speeds dropping off slightly on the south side of the storm. The subtropical ridge persisted over the Gulf of Mexico as Abby continued westward into Mexico.

At 200 mb., beginning on the 9th, moderate to strong easterly to southerly flow developed over the eastern Caribbean, with the appearance of a vigorous anticyclone off and to the east of the Windward Islands. This indicated strong outflow, and favored intensification of Abby, according to Riehl. On the 12th and 13th, this circulation had about disappeared, although a weak anticyclone persisted over Abby. By the morning of the 14th, the anticyclone at 200 mb. had again become more vigorous and, at the same time, Abby reintensified to full hurricane strength.

Abby appeared to be fairly well organized when it first formed and moved into the extreme eastern Caribbean. Reconnaissance and surface reports, particularly

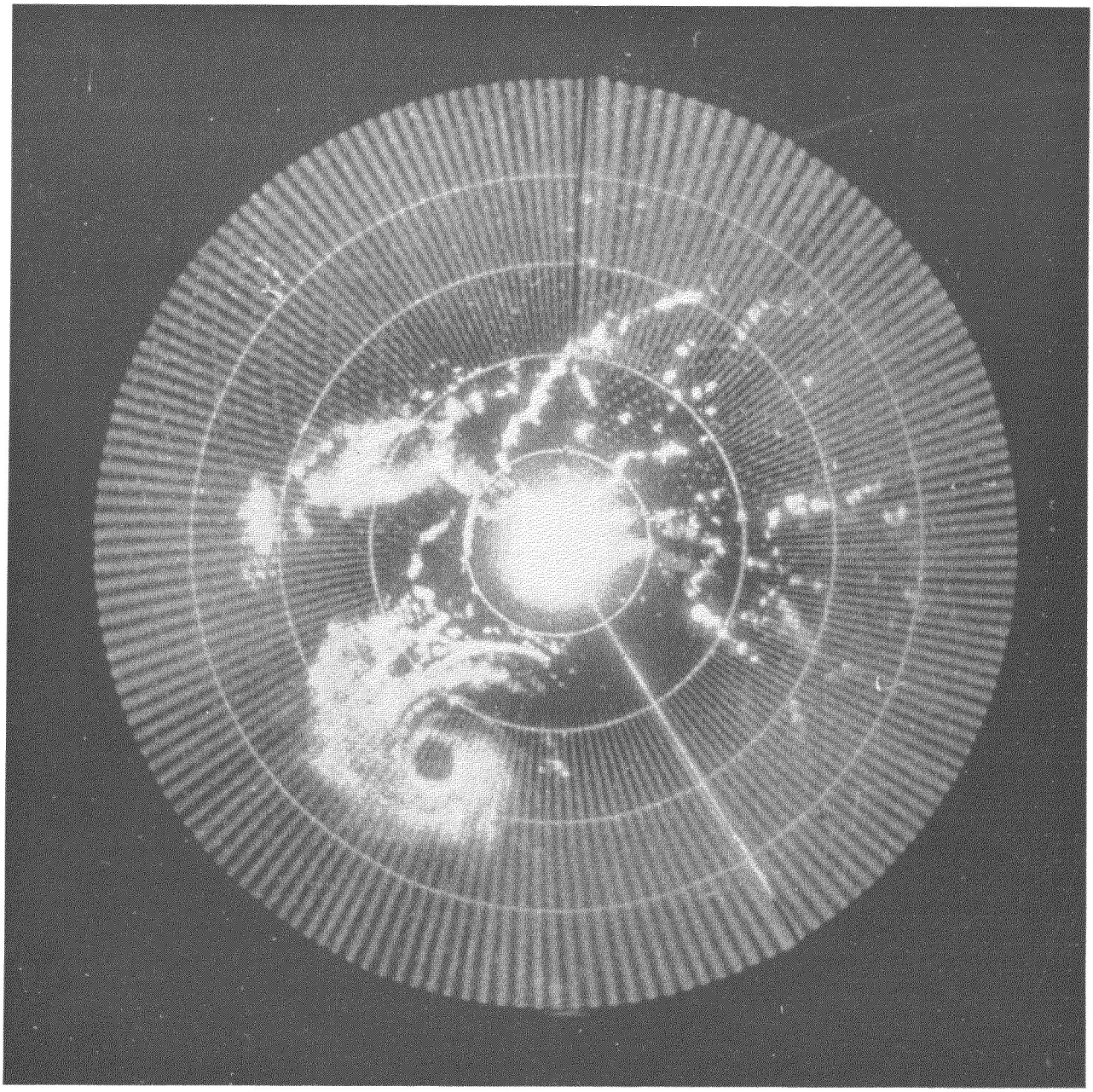

FIGURE 4.—Hurricane Abby on the morning of July 15 as it was approaching the coast of British Honduras. Note the complete wall cloud. Official U. S. Navy Photo.

on the 11th, 12th, and 13th, indicated a very small circulation, and a minimum of convective activity. This is possibly one reason for the loss of intensity. The area was covered with considerable stratified cloudiness, and radar coverage was difficult.

Peak wind gusts of 55 kt. were observed at St. Lucia when Abby passed about over the island, and the lowest pressure was 29.80 inches (1009.1 mb.). Rainfall was 6.80 inches in 24 hours. Martinique reported gusts of 66 kt.

Six lives were lost on St. Lucia when the roof of a house collapsed. Damage was estimated at $435,000 to property and banana and coconut plantations on St. Lucia. No estimate has been received from Martinique, however 33 percent of the banana and cane crop was lost, and considerable damage resulted to roads and bridges. Only slight damage occurred elsewhere in the Lesser Antilles. No loss of life has been reported from Central America. Property damage in British Honduras was light but damage to crops quite heavy.

Some remnants of Abby apparently continued across southern Mexico and developed into hurricane Celeste off the west coast [3].

*Tropical Storm Brenda, July 28-31.*—A weak cyclonic circulation that can be traced back to a position just off the southwestern Florida coast on July 27 began to deepen some 150 miles west of the Tampa Bay area the next day. By the night of July 28, pressure had dropped to near 1000

mb. as the Low began accelerating and moving northeastward onto the Florida coast southwest of Cross City. Thereafter the storm continued with gradually accelerating speed along the Carolina coasts on July 29, through the mid-Atlantic States on the 30th, finally passing through the New England States on the 31st and dissipating over southeastern Canada.

The storm was not officially named until the 29th when reconnaissance aircraft indicated tropical storm structure. Earlier aircraft and surface reports indicated rather light winds over an area within 50 to 100 miles of the lowest pressure. A tropical storm is usually associated with a zone of concentrated winds near the center, but not until the Low began accelerating northeastward and had reached the coastal area of the Carolinas was this type of pattern apparent.

Wind gusts in squalls to 60 m.p.h. were reported from many locations along the Atlantic coast and the central portion of the Florida Gulf coast. A gust of 65 m.p.h. was recorded at Cape Cod Canal, however, the highest sustained wind at an official Weather Bureau station was 58 m.p.h. at Cape Hatteras. The storm had no opportunity to reach hurricane force as the track was mostly over land after making landfall on the Florida coast.

Rainfall was heavy along the entire coast from Florida to Maine ranging from over 13 inches around Tampa to 4 to 6 inches in most other areas. There was considerable flooding in the west-central portion of the Florida peninsula. Elsewhere the rainfall was beneficial especially in the mid-Atlantic States.

Tides were not excessive due to the rather rapid movement of the storm and the fact that the center remained over or near land. While the storm was developing in the eastern Gulf, tides of 3 to 5 feet were reported along the Florida west coast in the Tampa Bay area and southwesterly winds in combination with high tides produced waves in excess of 10 feet with considerable erosion along the beaches.

Some traffic deaths have been associated with the heavy rains, however no deaths can be directly attributed to the storm. Total property damage was estimated near $5,000,000.

*Hurricane Cleo, August 17–20.*—Hurricane Cleo formed in a broad area of squally weather some 350 miles northeast of Nassau, Bahamas, on August 18. From surface considerations, the formation was unique in that a marked trough with at least one circulation center was present to the north of the area of formation. Thus, Cleo's development did not conform to the normal increasing easterlies and cyclonic vorticity in the north portion of the trough which usually accompany tropical cyclone development.

Hurricane Cleo remained small and moved about parallel to the Atlantic coast at an initial forward speed of 12 kt., later accelerating to 20 to 30 kt. It appears to have attained its greatest intensity as it approached southeastern New England when winds near the center were estimated at 80 kt.

Except during the early and late stages of the storm, there was never a good correlation between reported winds and central pressures. Wind reports from aircraft were consistently high compared with winds calculated from sea level pressures obtained by aircraft penetrations. Some compromise has been made and this accounts for the estimated sea level pressure noted on the storm track (fig. 1).

There was no known loss of life and very little, if any, damage directly attributed to this hurricane.

*Hurricane Donna, August 29–September 13.*—Donna, the one major hurricane of the season and the most destructive ever to strike Florida, was detected by aerial reconnaissance on the afternoon of September 2 near 14° N., 49° W. Maximum observed surface winds at that time were 120 kt. and there was a well-developed eye with a central pressure of 973 mb. The existence of a tropical storm or hurricane had been indicated earlier in the day by surface ships, apparently on the fringes of the circulation, which reported shifting winds up to 45 kt., and pressures as low as 1004 mb. Although lack of data makes it impossible to ascertain the exact time or place of increase to hurricane intensity, it seems likely that this occurred near 40° W. on September 1 and that the early stages of Donna were linked to disturbed weather near the African West Coast in late August. The passage of an active easterly wave through the area was suggested by unusually heavy rain at Dakar, with which the crash of an airliner there on August 29 was associated, and by heavy rain in the Cape Verde Islands on the 30th. An aircraft also reported indications of a tropical disturbance near 10° N., 24° W. on that date. Although no additional evidence of storm development was received until September 2, extrapolation of Donna's track back to the African coast gives reasonable continuity with these disturbed conditions. A study by Dunn [10] shows that tropical cyclones of the "Cape Verde" type typically behave in this manner, passing through the islands as unstable waves and attaining hurricane strength some 10° to 15° to the west.

On August 29 and 30 a ridge of anomalously-high surface pressure extended from near the Azores northeastward, a pattern long recognized [11] as associated with tropical cyclogenesis in the eastern Atlantic. The subtropical ridge at the 500-mb. level also was unusually strong during this period. However, it extended from northwestern Africa to the Azores; a northeastward protrusion toward western Europe was not so much in evidence as in some other cases of storm formation in this area. At the time Donna was discovered, a minor tropical depression was centered some 500 miles east of Bermuda, moving northward into a frontal trough. Thereafter, surface pressures began to rise to the north and northeast of the hurricane and for the next two or three days a ridge of above-normal pressure, surface and aloft, extended westward from just south of the Azores, preventing any marked meridional component of motion. Consequently, Donna continued toward the west-northwest on approximately the climatological track, but at a slightly faster-than-average rate

of about 17 kt. This course took the hurricane through the northern Leeward Islands during the evening of September 4 with the eye passing over Barbuda, St. Barthelemy, Sint Maarten, Anguila, and about 10 miles to the south of Anegada.

A slight decrease in intensity apparently occurred as the hurricane approached the Leeward Islands. The maximum sustained wind observed at Sint Maarten was 110 kt. and the lowest barometer reading 952 mb., compared to earlier reports from reconnaissance of 140-kt. winds and dropsonde measurements of 947 mb. Observers on the reconnaissance aircraft also had the impression that a slight weakening occurred September 5. However, no major changes took place during the first few days Donna was under observation and the radar presentation was characterized as that of an intense, "idealized" hurricane.

Only minor damage was reported at St. Thomas, Virgin Islands, with the wind reaching a gust speed of 52 kt. as the storm center passed about 35 miles to the northeast on September 5. Movement continued toward the west-northwest on the 5th and highest sustained winds were only 33 kt. at San Juan, P.R., as the hurricane passed some 85 miles to the north. However, high tides of 4 to 6 feet and heavy surf resulted on the northern and eastern coasts of Puerto Rico and serious floods developed over the northern and eastern portions of the island on the morning of September 6. Flood warnings had been issued following the detection by the San Juan radar of heavy rain moving in on the southern and eastern coastal sections on the evening of the 5th. However, despite the warnings, 107 persons were drowned. The greatest loss of life was at Humacao where 84 deaths occurred. The people in this area had returned to their homes, many of which were built on the river bed, after the hurricane center had passed to the north. According to reports, they failed to heed the subsequent flood warnings. The rain totaled 10 inches or more over a considerable area and measured over 15 inches on some of the mountain slopes.

The track of Donna from September 5 to 7 was affected by a short-wave trough passing to the north. There were temporary indications of recurvature at this time but the southern portion of the trough weakened, perhaps partially as a result of anticyclogenesis associated with the hurricane. Pressures north of the center continued to rise as the trough continued eastward and, as a result, the hurricane's course changed from west-northwest to west. In the meantime, Donna had more than regained any previous loss of intensity. The central pressure given by dropsonde was 940 mb. on the 6th and 944 mb. on the 7th.

Turks Island, in the southeastern Bahamas, escaped the full fury of the hurricane as it passed to the north, and highest winds were only 45–50 kt. However, rainfall was extremely heavy and amounted to over 20 inches, much of which fell in a 12-hour period. Several other islands in the southeastern Bahamas were less fortunate. The eye passed over or very near Mayaguana, Acklins Island, Fortune Island, and Ragged Island. No deaths were reported but only a few of the more substantial buildings were left standing in many of the island villages. At Mayaguana, which was battered by hurricane-force winds for 13 hours, many of the residents took shelter in buildings of the missile-tracking base. The maximum winds in Donna at this time are not known with certainty. At Ragged Island the anemometer failed at 130 kt. The observer estimated the maximum at Fortune Island at 150 kt. after the anemometer and supporting tower blew away. Most of the islands in the western Bahamas were somewhat north of the storm track and no extensive damage resulted although Andros Island experienced hurricane winds for several hours.

On September 9, Donna skirted the northeastern coast of Cuba, bringing gales and heavy rains to much of the island, then took a west-northwest course, toward the Florida Keys. The center crossed over the middle Keys just northeast of Marathon between 0200 and 0300 EST on September 10. It is estimated that sustained winds near the center reached 120 kt. and momentary gusts were at least 155 kt. The central pressure had continued to drop as the hurricane moved across the warm waters of the Florida Straits and was approximately 930 mb. when the center reached the Keys. Miller [12] has made computations relating the probable minimum pressure to temperatures of the underlying water surface. His calculations indicate that a temperature of 86° F. would be required to produce a central pressure of 930 mb. It is of interest to note that there are only a few areas in the hurricane belt, mostly in the Gulf of Mexico and near the Florida Keys, where such high sea-surface temperatures are likely, and that the lowest pressure ever recorded in the Western Hemisphere (892 mb.) occurred in the Keys Hurricane of 1935.

Shortly after it passed the longitude of Puerto Rico, Donna slowed considerably in forward speed and moved at 6 to 10 kt. until it reached the Florida Keys on the 10th. There were many light and variable winds in the middle and upper troposphere and the steering pattern during this period was never clearly defined. At 0700 EST on September 8, when the hurricane was located only 380 miles southeast of Miami and moving westward at about 10 kt. *the Miami wind at 500 mb. was still blowing from the west.* It seems evident that there was a contribution from the storm itself to its movement.

On September 10 a low pressure system was moving across southeastern Canada with a cold front extending through New England thence southwestward, becoming stationary from Tennessee to Texas. No marked surface-pressure trough accompanied the front south of about 40° N. However, at about this time, the ridge of high pressure which had persisted to the north of the storm began to decay. This occurred in response to an upstream increase in amplitude in the westerlies and the establishment of a long-wave trough in the east-central United States. As a result, Donna began recurvature at this point and moved northwestward along the southwestern coast

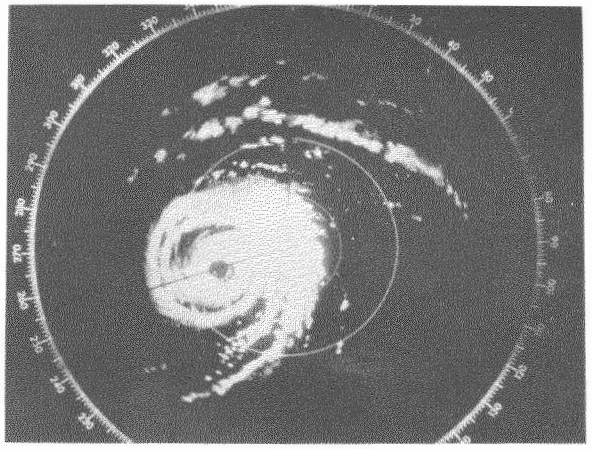

FIGURE 5.—Radar picture of Donna at its closest position to Miami, illustrating all the features of the classical hurricane. 0730 EST September 10, 1960; strobe 100 n. mi.

of the Florida peninsula. The eye passed over Naples and Fort Myers as the hurricane turned northward, moved inland, and then continued northeastward to re-enter the Atlantic just north of Daytona Beach about 0400 EST, September 11. Sustained winds of over 90 kt. with gusts of 100 to 130 kt. probably occurred on the lower west coast from Everglades City to Naples and there were sustained winds of near hurricane force with higher gusts near the center as it moved across the peninsula. Despite the trajectory over land and a filling of central pressure from 950 mb. at Fort Myers to 970 mb. on the east coast, the storm was still intense and well organized when it moved into the Atlantic again.

The storm surge on the Florida Keys reached as much as 13 feet above normal levels and was generally 8 to 12 feet some 40 miles to the northeast of the track and 20 miles to the southwest. Destruction from the combination of wind and water in this area ranged from major to almost complete. Tide departures tapered off to the north to 3 to 4 feet above normal in the Miami-Palm Beach area. On the southwestern Florida coast, the storm surge was locally up to 11 feet above normal. The surge reached as far north as Naples, and Fort Myers reported levels 4 to 7 feet above normal. On the Gulf coast north of Bradenton and the Atlantic coast north of Palm Beach, tides were mostly 1 to 3 feet above normal. Maps showing the high water marks recovered in the Florida Keys and along the west coast of Florida will be presented in a forthcoming article, by D. L. Harris, in the *Review*.

The effect of the hurricane on the flora and fauna of the Everglades National Park is being studied by specialists in these subjects. The largest stand of big mangrove trees in the world is located here and was about 50 percent or more killed, with a complete kill in some areas for reasons which are not yet wholly understood. Almost all large mangrove trees which survived the 1935 hurricane were killed by Donna. This is true to a somewhat lesser extent of the mahogany trees. It is interesting to note that new mangrove trees growing after the 1935 hurricane were not as large as those standing in 1935 indicating a longer period free from major hurricane occurrence prior to 1935 in this area. The great white heron, only found in the United States in extreme southern Florida and once in danger of extinction, suffered about a 35 to 40 percent loss but about 600 birds remain. One of the two or three largest nesting concentrations of the American bald eagle in the United States, exclusive of Alaska, is also in the Park. All eagle nests were destroyed but four months later some twelve had been rebuilt.

Figure 5 shows a radar picture at the time Donna was closest to Miami. Present are the features of the classical hurricane. The round eye about 21 miles in diameter and the thick wall cloud some 17 to 20 miles in diameter are observable. At the time, the heavy rain band visible over the Miami station was producing rain at the rate of about one inch per hour.

Donna began a gradual acceleration as it moved through northeastern Florida and was advancing at about 12 kt. when it passed into the Atlantic. Rapid re-intensification occurred over the ocean and when the center was about 80 miles southeast of Charleston, S.C., on the afternoon of September 11, the SS *Mae* reported winds of 105 kt. and 20- to 30-foot seas. Several small brief tornadic storms were reported in coastal South Carolina with about ten people hospitalized and considerable property damage in the Charleston area. Winds along the beaches near Charleston reached about 60 kt. in gusts. However, the coastal section near the North Carolina inc received sustained hurricane-force winds.

A short-wave trough was moving through the Great Lakes region on September 11 and, under the influence of an increased southerly flow, Donna accelerated to a speed of about 30 kt. toward the northeast, reaching the North Carolina coast just northeast of Wilmington during the evening of the 11th, then passing into the Atlantic again near the Virginia line about 0500 EST of the next morning. During its passage over North Carolina, Donna's eye was unusually large with the area of calm or light variable winds ranging from 50 to 80 miles in diameter. Some small-scale irregularities in speed and direction of motion during this period may be partially attributable to differential friction between land and water. Such an effect was suggested as the cause of erratic behavior of some of the 1955 hurricanes in this area [13]. Minimum pressures reported along this section of the track ranged from 958 to 967 mb. and highest winds were in the 70-90-kt. bracket with some estimates of 100-kt. gusts. Tides reached 4 to 8 feet above normal at various places along the North Carolina coast and waves were reported from 15 to 20 feet. Several small tornadoes or locally destructive storms occurred in the forward portions of the hurricane and at least eight persons required hospitalization. Five other tropical storms have taken rather similar tracks across North Carolina in the past decade and Hardy [14] reported that residents in a few areas felt that Donna was the most destructive. He points out, however, that this is probably true only in limited sections in the northeastern portion of the State.

When Donna again reached the ocean, it resumed its rapid movement with a forward speed of 30 to 35 kt., moving northeastward a short distance off the coast and crossing Long Island shortly after noon on September 12. Winds of about hurricane force, but with gusts locally to about 90 kt., brushed the Maryland, Delaware, and southern New Jersey coasts. Residents at Ocean City, Md., described the storm as the worst in the city's history. Damage to property in other areas along the immediate shore was heavy and considerable agricultural losses were suffered inland.

Sustained winds reached about 90 kt. at several points on Long Island and 50 to 60 kt. on western Long Island and in New York City. Gusts of 100 kt. or higher were reported at Montauk, L.I., and Block Island, R.I., and peak gusts reached or exceeded hurricane force east of the center through southern New England and northward to the New Hampshire coast area. Winds to the west of the track were somewhat less and there were no sustained hurricane-force winds reported on the mainland in New England except for isolated cases where local topographic effects were responsible. One such exception was a sustained 80-kt. wind, with gusts of over 120 kt., at Blue Hill Observatory at Milton, Mass. The minimum central pressure recorded at Brookhaven, L.I., was 961 mb., approximately the same as the minimum along the track through North Carolina. Gradual filling and weakening occurred farther north as the center continued rapidly northeastward, moving through Maine just west of Caribou and into Canada late on September 13. Winds of hurricane force still persisted in squalls near the center until about the time it reached the Canadian border. The storm then moved northeastward through Labrador and into the Atlantic as a weakening frontal disturbance. Complete meteorological data for individual stations in the hurricane's path can be found in *Climatological Data, National Summary* for September 1960.

There was evidence that Donna was beginning to assume extratropical characteristics as early as September 12. Many of the maximum winds reported in the Middle Atlantic States were from the northwest, indicating that cooler, dryer air was beginning to invade the circulation. Another feature contributing to peculiar distributions of wind and pressure extremes was the unusually large eye of Donna. During the period the hurricane was moving from North Carolina to southern New England this was as much as 50 to over 100 miles in diameter, an extreme and probably unprecedented size for a hurricane eye.

Tides were well above normal along the entire Middle Atlantic coastline and ranged about 6 feet above normal near Atlantic City, N.J., and in the New York City-Long Island area. Departures of 5 to 10 feet above normal occurred along the southern New England coast but fortunately the damage potential was lessened by the arrival of the storm surge at the time of normal low tide. Even so, considerable damage to coastal properties was reported all along the Middle Atlantic and New England coast as a result of combined effects of winds and tides and there were extensive damages from flooding farther inland, particularly from the Catskills to Long Island. A map showing the peak tide and peak surges in New York and southern New England will be given in a forthcoming article, by D. L. Harris, in the *Review*.

Donna was unique in that it gave hurricane force winds to Florida, the Middle Atlantic States, and New England. However, although it was one of the most destructive hurricanes of all time, loss of life was remarkably low. This can be attributed to three factors—timely and accurate warnings, effective dissemination by news media and other agencies, and the taking of proper precautions by the public. The accuracy of the warnings is in large part a reflection of the continuous tracking by aircraft reconnaissance and land-based radar, which was probably the most complete of any hurricane in history.

Results of the various objective forecast techniques ranged from poor to excellent with median 24-hour errors for the individual methods ranging from 68 to 132 n. mi. The results of the various systems cannot be compared since the number of forecasts and the times of the forecasts with each were not the same, being dependent on the available data. Each method, including the one with the lowest median error, showed serious errors during at least one of the three critical periods—the abortive recurvature off Puerto Rico, the recurvature over Florida, or the acceleration off the Atlantic coast.

*Hurricane Ethel, September 14–17.*—Hurricane Ethel developed rapidly in the central Gulf of Mexico early on September 14. Its position and intensity were established by the 0930 CST report from MAMOS (Marine Automatic Meteorological Observing Station) in the central Gulf of Mexico. The hurricane moved northward and continued to intensify rapidly during the day with a central pressure of 972 mb. and winds of 140 kt. reported by reconnaissance aircraft that afternoon. During the night of September 14–15, cool dry air entered the circulation and the hurricane's intensity diminished quickly. The hurricane center reached the coast near Biloxi, Miss., with the lowest pressure 981.4 mb. during the afternoon of September 15 at Keesler Air Force Base. It continued to weaken as it moved northward through eastern Mississippi that night. The remnants of the storm were located in central Tennessee on the morning of September 17.

The highest sustained wind reported by a land station was 78 kt. with gusts to 90 at Venice, La., at 0415 CST, September 15. Burrwood, La., reported winds of 45 kt. with gusts to 60. The highest tide reported was 7 feet above mean sea level on Quarantine Bay on the east side of the Mississippi River about 0400 CST on the 15th. Tides of 2 to 5 feet above mean sea level occurred from the mouth of the Mississippi River eastward to St. Marks, Fla. Local rains of 5 to 6 inches or more were reported through southeastern Mississippi, southwestern Alabama, and extreme northwestern Florida but no significant flooding occurred.

The total storm damage probably did not much exceed one million dollars and there was no loss of life.

*Tropical Storm Florence, September 17–26.*—An extensive shower area was noted well to the northeast of the Leeward Islands September 16 although there were no indications of a definite circulation. By the morning of the 17th, pressures through the eastern Antilles had fallen 3 to 5 mb. with light south and southwest winds indicating the possibility that a circulation had developed. On the evening of the 17th, reports from shipping to the north of Puerto Rico placed a closed circulation near 21° N., 66° W. with winds up to 35 m.p.h. The Low continued westward about 10 m.p.h. and reconnaissance aircraft located a broad, ill-defined center with maximum winds around 40 m.p.h. on the morning of the 18th near 21° N., 69° W.

Tropical Storm Florence moved on a west to west-northwest track near 12 m.p.h., gradually weakening until the 20th when reconnaissance aircraft found only a weak Low south of Andros Island in the Bahamas with no significant weather or strong winds. The remains of Florence moved into the western end of Cuba and became nearly stationary until the evening of the 22d when conditions became more favorable for redevelopment. The Low began moving northeastward and was located just off the southwestern Florida coast by the morning of the 23d with winds up to 30 m.p.h. and widespread rain over southeastern Florida. It then became blocked by a large high pressure system along the mid-Atlantic coast after reaching the vicinity of Lake Okeechobee the evening of the 23d and changed to a west-northwest track, drifting into the eastern Gulf of Mexico near Tampa early on the 25th. The Low continued quite weak over the Gulf and moved into the Pensacola area on the morning of the 26th with winds less than 25 m.p.h. but with a rather large rain area that covered the southern portions of Alabama and Georgia and northwestern Florida.

Florence was never a well-defined tropical storm and maximum winds were just barely of tropical storm intensity (for only a short period) although gusts to 52 m.p.h. were reported in the Vero Beach area in a squall when the Low was nearest that station. The only significant damage in this storm was from local flooding in Florida. Rainfall totals of 3 to 6 inches or more were reported during passage of the Low on ground that was already saturated from the previous heavy rains of Donna. Monthly totals for September were well over 20 inches at many spots in southeastern Florida with a few totals in excess of 30 inches. No damage of consequence was reported over the eastern Gulf States with rainfall probably beneficial to crops. No known fatalities or injuries have been reported.

REFERENCES

1. C. M. Woffinden, "The Weather and Circulation of June 1960," *Monthly Weather Review*, vol. 88, No. 6, June 1960, pp. 229–234.
2. H. Riehl, *Tropical Meteorology*, McGraw-Hill Book Co., Inc., New York, 1954, 392 pp. (pp. 226–227).
3. R. A. Green, "The Weather and Circulation of July 1960," *Monthly Weather Review*, vol. 88, No. 7, July 1960, pp. 257–262.
4. G. E. Dunn and B. I. Miller, *Atlantic Hurricanes*, Louisiana State University Press, Baton Rouge, La., 326 pp. (p. 35).
5. L. P. Stark, "The Weather and Circulation of August 1960," *Monthly Weather Review*, vol. 88, No. 8, Aug. 1960, pp. 286–293.
6. E. M. Ballenzweig, "Seasonal Variations in the Frequency of North Atlantic Tropical Cyclones Related to the General Circulation," *National Hurricane Research Project Report* No. 9, Washington, D.C. July 1957.
7. E. M. Ballenzweig, "Relation of Long-Period Circulation Anomalies to Tropical Storm Formation and Motion," *Journal of Meteorology*, vol. 16, No. 2, Apr. 1959, pp. 121–139.
8. C. F. Tisdale, "The Weather and Circulation of September 1960," *Monthly Weather Review*, vol. 88, Nos. 9–12, Sept.-Dec. 1960, pp. 353–361.
9. J. F. Andrews, "The Weather and Circulation of October 1960," *Monthly Weather Review*, vol. 89, No. 1, Jan. 1961, pp. 24–30.
10. G. E. Dunn, "Areas of Hurricane Development," *Monthly Weather Review*, vol. 84, No. 2, Feb. 1956, pp. 47–51.
11. E. B. Garriott, "The West Indian Hurricanes of September 1906," *Monthly Weather Review*, vol. 34, No. 9, Sept. 1906, pp. 416–423.
12. B. I. Miller, "On the Maximum Intensity of Hurricanes," *Journal of Meteorology*, vol. 15, No. 2, Apr. 1958, pp. 184–195.
13. G. E. Dunn, W. R. Davis, and P. L. Moore, "Hurricanes of 1955," *Monthly Weather Review*, vol. 83, No. 12, Dec. 1955, pp. 315–326.
14. A. V. Hardy, "Hurricane Donna in North Carolina," *Weatherwise*, vol. 13, No. 5, Oct. 1960, pp. 213–214.